## III. *On the Elasticity of the Lungs. By* James Carson, *M. D. Communicated by* Thomas Young, *M. D. For. Sec. R. S.*

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In a Treatise which I published a few years ago on the motion of the Blood and the mechanism of Respiration, it was contended, that a cause essential to the performance of these functions, had escaped the notice of physiologists. This cause was stated to be the elasticity or resilience of the lungs. The resilient property of the substance of the lungs had indeed been admitted by all anatomists and physiologists; and it is commonly demonstrated in the lecture room, that, if a piece of the substance of the lungs be cut out and stretched, it will recover its former dimensions when released from the extending power. But though the existence of this property had been universally admitted, no physiologist had attempted, so far as I know, to explain the means by which nature had contrived to render it subservient to the purposes of life. The statement and explication of this contrivance, with reference at least to certain purposes, constitute in a great measure the subject of the treatise to which I have alluded. Although it was proved in that Treatise, that, for the performance of those movements in which life is acknowledged chiefly to consist, a power of considerable extent is derived from the elasticity of the lungs, it was at the same time confessed, that no data had been discovered, from which the full

extent of that power, as it is applied in the living system, could be calculated.

It was conceived that it would be a matter of no small importance to ascertain the extent of a power which, as I believe, discharges a part of the first importance in the scheme of life. With that view, a number of experiments have been performed, which I hope will be found to determine, in a considerable number of animals, the extent of the elasticity possessed by the lungs in their state of expansion in the living and sound body; or the extent of a power by which the heart and diaphragm, and perhaps various other organs, are as necessarily and as effectively influenced as the piston of the steam engine is by the expansive powers of steam.

To enable those Gentlemen who may not be familiar with the anatomy of the parts concerned, to perceive the tendency and import of these experiments, and to understand the arguments that may be advanced, it may be necessary to premise the narration with a short and general description of the structure, position, and connections of the lungs. It is hoped that no person, who has at all applied his attention to mechanical philosophy, will find any difficulty in comprehending this description of a simple but beautiful machinery.

The appearance of the lungs, or, in common language, the lights of oxen and of other animals slaughtered for the use of man, is familiar to every one. They are that irregular pale red spongy mass, which is daily seen suspended in the shambles by the windpipe. The windpipe, or in the language of anatomists, the trachea, which is a necessary appendage to the lungs, extends from the throat to the top of the chest.

It is composed of a succession of cartilaginous rings, which nearly form complete circles. Each ring is connected to the next to it in succession by a strong elastic membrane. A small segment is cut off from each of those rings behind, where the place of cartilage is supplied by the same strong elastic membrane by which the rings are connected. By this contrivance the rings may be expanded, and the diameter of the windpipe is rendered susceptible of variation as well as its axis.

As soon as the windpipe has fairly entered into the confines of the chest, it divides into two branches, one of which proceeds to the right and the other to the left side. These branches possess the same structure with the windpipe itself, and each as it proceeds is divided into smaller branches, which again and again ramify into others still smaller. The branches for some time are formed like the trunk from which they proceed, but at length they drop the cartilaginous structure, and become simply membranous tubes. These tubes ultimately terminate in cells, between which there is a free passage for the air. The interstices between these tubes and cells are filled up by glands, the common cellular substance, and by blood vessels and nerves. The whole of this mass is enveloped in a fine membranous covering, termed the pleura pulmonalis, which however is impervious to the air. To each of the two original divisions of the windpipe a distinct lung is appended, called the right and left, between which there afterwards exists no communication.

The lungs occupy that part of the animal frame denominated the chest. This, in man, is the upper part of the trunk of the body. The shell of the chest is composed of bone,

cartilage, muscular substance, and membrane. Behind, on each side, and in front, it is osseous. It is fenced by the spine behind, by the breast bone in front, and on each side by a tier of ribs, which are connected at one end to the spine by articulations, and at the other end to the breast bone by elastic cartilages. The intercostal muscles secure the spaces between the ribs. The ribs on one side with the corresponding ribs on the other, and with the intervening parts of the spine and breast bone, form the circumferences of so many circles. The circle formed by the junction of one rib with its corresponding rib on the other side, is largest at the bottom, till at the top it is reduced to so small a diameter, as to serve for little more than a passage for the windpipe and gullet. Strong muscles and tendons traversing each other from the upper rib on one side to that on the other, and to the vertebræ of the neck and to the clavicles, and connected by a union of membranes with the exterior surface of the tubes, to which they afford a passage, form the secure boundary of the chest at the top. The form of the chest is evidently conical. The floor or base of this cone is formed by a thin circular plate, partly fleshy and partly membranous, but every where flexible and yielding, with its rim all around firmly concreted with the shell of the chest. It is called the diaphragm or midriff. It cuts the trunk of the body transversely, and separates the cavity of the chest just described from that of the belly. One condition of this flooring is worthy of particular notice. Its area is more extensive than that of the largest transverse section of the chest. In consequence of this, it admits of motion to a considerable extent; and, for reasons which will be afterwards explained, assumes in the

living and sound state of the parts, the form of a cone, of which the apex looks towards the chest.

The form of the diaphragm, or base of the chest, may be illustrated by the comparison of a wine bottle; the bottom of which is convex inwardly and concave outwardly; the diaphragm bearing in form and position the same relation to the chest, which the bottom does to the rest of the bottle.

The cavity above the diaphragm is chiefly filled by the lungs, which therefore in the living system occupy a space nearly as large as the shell of the chest.

As soon, however, as the chest has been opened, and the external surface of the lungs exposed to the contact of the circumambient air, these organs shrink into dimensions far less extensive than those which they occupy in the living body.

The causes of the lungs being expanded in life into larger dimensions than those which are natural to them, or which they occupy when they have been extracted from the body, are curious and important, and may be thus explained.

The walls or boundaries of the chest are well secured. They are at several places indeed perforated by tubes, but these tubes, at the place of their entrance or exit, are, as has been described, always securely concreted by an union of membranes with the substance of the chest. The chief of these perforations are made by the windpipe, the gullet, and some large blood vessels at the top; and at the bottom, by the gullet again in its passage out of the chest, the great descending aorta, and the inferior cava. Conceive then, the lungs to be placed in this cavity in such a manner that the windpipe should pass out of it at the top, having its exterior

surface well secured to the part of the chest at which it passes, but affording, in consequence of its cartilaginous and incompressible structure, an open passage into the interior substance of the lungs, and conceive that no substance should exist between the exterior surface of the lungs, and the internal surface of the chest. The pressure of the atmosphere, it is evident will, in these circumstances, necessarily bring the external surface of the lungs into contact with the whole of the interior surface of the chest; but as the walls of the chest are strong and incompressible, and as the lungs are pliant and dilatable, the lungs are necessarily expanded to the dimensions of the chest, which remain nearly the same. But the lungs, though dilatable, are powerfully elastic; and, when distended to the dimensions which they are thus forced to occupy, their substance is stretched far beyond its natural condition. As soon, however, as the full weight of the atmosphere shall be allowed to ponderate upon the external surface of the lungs, and an equal pressure shall be sustained by their exterior surface and the interior surface of the air vessels, of which their substance is composed, a condition which will arise as soon as the air shall have obtained a free passage through the walls of the chest to the external surface of the lungs; these organs will then shrink into the dimensions which are prescribed to them by the nature of their structure. To ascertain, then, the extent of the power required to distend the lungs to the dimensions which they occupy in the sound system, or, in other words, the extent of that force by which the walls of the chest are pressed, or, in popular language, sucked inwards, in consequence of the resilience of the lungs, is the object of the following experiments.

For the purpose of these experiments, an apparatus of glass, of the following simple construction, was used. An oblong glass globe, containing nearly two quarts, had tubular openings at each end, A, and B. (Plate IV.) A glass tube, nearly three feet in length, and bent at one end, was joined by the blowpipe to the opening at B, and is represented by B, C. To the other opening at A, a shorter tube was joined in the same manner, and in the form A, D. A free passage was established from D to C, where the tubes were both open. To D, a piece of the dried gut of some small animal was bound, of a few inches in length. The other end of the gut was fixed to a cylindrical tube of bone, metal, or wood, also of a few inches in length, and of a diameter corresponding with the diameter of the windpipe of the animal which was to be the subject of the experiment. The windpipe of an animal, which had been recently killed, was divided across near the throat, and separated by dissection from the rest of the neck, nearly to the top of the chest.

The first experiment was made on the 27th of August, 1817, on a cat, which had been hanged the day before. A small cylindrical tube of bone attached by gut to the end of the glass tube, A, D, was inserted into the windpipe, which had been prepared in the way described, and which was tied to the cylinder so tightly, that no air could pass between the external surface of the tube and the internal surface of the windpipe. An open and secure passage was thus established between the glass apparatus and the windpipe, and of course the lungs of the animal. Water was then poured into the apparatus at C, until it stood in the upright tube C B, at the height of eleven inches above the level of the water in the

glass globe. An opening was then made through the chest of the animal on each side, and the air admitted into contact with the external surface of both lungs. The water instantly sunk about two inches in the upright tube, and the lungs were gently pressed out at the openings. Hence it was inferred, that the spring given to the air by the pressure of a column of water nine inches high, was stronger than the elasticity of this animal's lungs expanded to the dimensions of the chest. To my surprise and disappointment, the water began to sink still lower in the glass tube, and stood at last at the height of an inch above the level of the water in the globe, and the lungs at the same time gradually collapsed. Water was again poured into the upright tube, till it stood for a few seconds at the height of nine inches above its level in the globe, and the lungs again filled the chest. Upon applying the ear to the openings, the cause of the collapse of the lungs was discovered. The sound of air was distinctly heard pressed from the lungs at the openings. Hence it was concluded, that the pleura pulmonalis had been wounded in opening the chest.

On the 28th of August of the same year, a bullock recently slaughtered was made the subject of experiment. The same apparatus, using only a pipe of a larger diameter to be inserted into the larger windpipe of the animal, was applied as in the preceding case. Water was poured into the upright tube at C, until it stood at the height of one foot above the level of the water in the globe, and at that of four inches from the top of the tube. Openings were then made in the chest to admit the air. The water instantly rose in the tube two inches higher, and remained stationary at that point. The

lungs, to appearance, were nearly collapsed to the usual degree. It was evident, from the ascent of the water in the upright tube upon the chest being perforated, that the spring given to the air by being compressed by a column of water twelve inches high, was not sufficient to balance the elasticity of the full dilated lungs of this animal. Water was poured into the apparatus till the tube remained filled. The lungs, with this additional pressure, still continued much shrunk. As the height of the tube was not great enough to ascertain the extent of the pressure necessary to balance the resilience of the lungs of animals of this size in the state of their usual expansion in the living body, an alteration in the apparatus became necessary.

On the 11th of September, 1817, a bullock was made the subject of experiment, with an apparatus of the same kind, but with a taller upright tube. Water was poured into the apparatus till it stood in the upright tube twelve inches above its level in the globe. The thorax was then opened. The water instantly ascended an inch and a half, and remained stationary. More water was then poured into the apparatus; but when it had risen an inch higher in the tube, the globe was found to be full. A further alteration therefore in the apparatus becomes necessary, before the resilience of the fully distended lungs of an ox can be ascertained; for the lungs continued shrunk to a considerable degree, in opposition to the spring of air compressed by a column of water of fourteen inches in height.

On the same day another bullock, with a less capacious chest, was made the subject of experiment with the same apparatus. Water was poured into the apparatus, as in the

preceding instances, till it stood sixteen inches above the level of the water in the globe. An opening was then made into the abdomen. A fold of the fleshy part of the diaphragm was then drawn down on each side, and care being taken that no part of the lung was included in the fold, it was cut into. The sound of a current of air pressing through the openings into the chest was distinctly heard, and the water in the upright tube arose instantly to the height of eighteen inches above the level of the water in the globe. The diaphragm, before the openings, was still tense, and slightly concave towards the belly; but after that it became lax, wrinkled and flat. Some additional water was poured into the apparatus; but we were prevented in this case, as in the preceding, from ascertaining the amount of the force requisite to distend the lungs to the dimensions which they usually occupy in the living animal, by the deficient capacity of the glass globe.

By these experiments, I think it is clearly ascertained, that the spring of air compressed by a column of water of a foot and a half high, is not equal to the resilience of the lungs of an ox, at the usual stage of their dilatation.

In all these experiments, the oxen were placed upon the back with the shoulder raised a little above the rest of the body: some share of the collapsing effort of the lungs might be imputed to their specific gravity. But when the levity of the lungs is considered, and also that they were observed not to shrink more from the breast to the spine than from the diaphragm to the neck, in opposition in this case to gravity, and that their dimensions were not increased, nor their form varied by any change of position; little of the resistance which

the lungs made to the spring of the contained air, is imputable, I think, to their specific gravity.

On the 16th of September, 1817, the apparatus was applied to a calf. When the water in the upright tube had reached the height of fourteen inches above its level in the globe, the lungs appeared to be distended to the full capacity of the chest. Upon cutting off the communication between the apparatus and the animal, the water instantly fell to its level, and the lungs shrunk into very small dimensions. The animal, in this experiment, was placed with the chest erect, so that the shrinking of the lungs upwards from the diaphragm to the neck, and which was observed to be as great as in any other direction, must have taken place in opposition to the specific gravity of the lungs.

In almost every experiment in which the chest was perforated by a sharp instrument, the lungs were found to be wounded, and the object in a great measure defeated. In the experiment about to be described, and the last which will be detailed at this time, great care was taken to prevent the accident now mentioned.

On the 31st of October of the same year, the apparatus was applied to the prepared trachea of a dog, which had been hanged on the preceding day. Water was poured into the apparatus until it stood in the upright tube at the height of six inches above its level in the globe. The abdomen of the animal was opened, and the diaphragm freely exposed. A part of the muscular substance of the diaphragm was drawn down in a fold, which was done without difficulty; and care being taken that no part of the lung was contained in the

fold, an incision was made into it. This was done on both sides. The water ascended instantly about an inch in the upright tube, and the lungs were found to have receded from the openings. Water was poured into the apparatus, until its level in the tube stood above that in the globe at the height of ten inches. The openings in the diaphragm were carefully extended along the chest, and the lungs exposed freely to view. They were now apparently dilated to the boundaries of the chest. In this experiment, the water in the tube remained steadily at the same height, and the lungs continued fully dilated. In those experiments in which the water was observed to descend slowly, and the lungs to collapse gradually, it is very evident, that the lungs must have been wounded, so as to allow some air to escape through the pleura.

The appearance which the lungs exhibited in this situation was novel and interesting, and was no doubt the same which they would have exhibited in the living body, had it been possible to bring them into view. Their surface was smooth and polished, and their edges rounded, without any of those corrugations and sharp angles which they usually exhibit. Their colour was red, and life-like. They felt firm to the touch. The heart appeared like a bird nearly covered by its nest.

The state of the diaphragm in this experiment was worthy of remark. Before the incisions were made into it, it still exhibited a degree of concavity towards the belly, but not with the same degree of tenseness which it is generally observed to possess; for a fold of it was taken with ease,

which in ordinary cases, before the chest has been opened, is done with difficulty. As soon as the openings were made into the diaphragm, it became lax, flat, and corrugated.

Frequent repetitions of these experiments, and much care and accuracy in conducting them, would be required, before the amount of the resilience of the lungs, in all the conditions in which it may be supposed to exist, could be estimated. But defective as these experiments in many respects are, the object, for which they were instituted, seems to have been fully attained by them. In the Inquiry into the causes of the motion of the blood, it was contended, that the elastic substance of the lungs, in consequence of the degree to which that substance was stretched in the living body, generated a permanent power of great extent, and that this power was employed by nature to circulate the blood, and to carry on the process of respiration. The existence of this power was inferred, from the elastic property of the substance of the lungs themselves; from the space which those organs must fill in the living body; from the phenomena exhibited upon opening the chest and admitting the external air; and from the ebullition on the surface of the water into which the inverted windpipe of an animal had been inserted, as soon as the lungs were allowed to collapse. In the various examinations which my opinions have undergone, the existence of this power has been admitted, and the claim to priority in the detection and application of it freely conceded to me; but it has been contended, that the amount of it, in some instances, is inconsiderable, and consequently that the effects ascribed to it have been greatly over-rated. By these experiments, the power has been proved to be greater, than my anticipations even made

it, and fully adequate to all the important offices which I have ventured to assign to it. From a defect in the apparatus, the extent of the power in question could not be ascertained in the lungs of oxen and animals of their size; but it was proved to exceed, considerably, the force necessary to support a column of water of a foot and a half in height above its level. In calves, sheep, and in large dogs, the resiliency of the lungs was found to be balanced by a column of water varying in height from one foot to a foot and a half, and in rabbits and cats, by a column of water varying in height from six to ten inches.

The method by which nature has contrived to apply this powerful engine to the heart and diaphragm, I have attempted to explain at length in the treatise already mentioned. In a preceding part of this paper, however, I have stated, that during the life of the animal, and after death, until an opening shall have been made into the cavity of the chest, the diaphragm assumes the form of a cone, and that the causes of this phenomenon would be afterwards pointed out. The brief explanation which is now to be given of this appearance, will afford, at the same time, a perspicuous view of some of the important purposes to which, in my opinion, nature has turned the elasticity of the lungs.

While the chest is in a sound state, a balance of atmospherical pressure ponderates against the external surface of its walls; or these are pressed inwards more than they are pressed outwards by a given weight. The shell of the chest possesses sufficient stability to resist this pressure without changing in any considerable degree its form and capacity at all parts, except at the base, or diaphragm; which being

muscular, pliant, and of a more extensive area than that of the transverse section of the chest, is in consequence of the greater weight sustained by its outward or inferior surface, necessarily pressed, or, in popular language, sucked upwards in the form of a cone. The extent of this cone will be necessarily regulated by the extent of the area of the diaphragm, compared with that of the area of the transverse section of the chest. But the contraction of the muscular fibres of the diaphragm diminishes its area, and reduces it to a nearer equality with the area of the transverse section of the chest, and thus diminishes the magnitude of the diaphragmatic cone, and in an inverse proportion enlarges the boundaries of the chest. But the diaphragm at the succeeding relaxation of its fibres, is restored to its former dimensions; becomes capable of being swelled into a larger cone; and, by this encroachment, reduces the boundaries of the chest to their former limits.

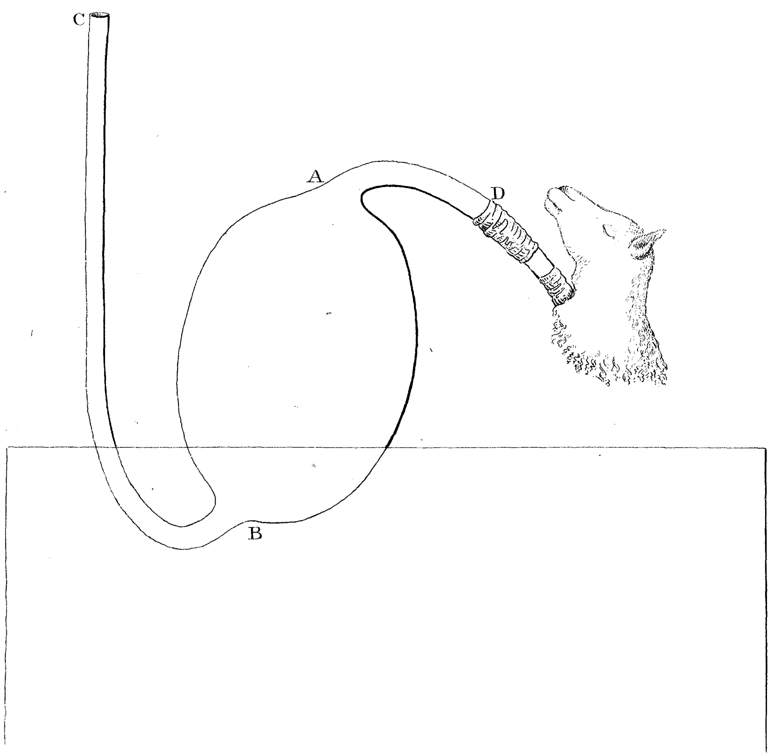
Two powers are therefore concerned in regulating the movements and in varying the dimensions and form of the diaphragm, the elasticity of the lungs, and the contractile power of the muscular fibres of the diaphragm. Of these powers the one is permanent and equable, the other variable and exerted at intervals. The contractile power of the diaphragm, when fully exerted, is evidently much stronger than its antagonist, the resilience of the lungs; but the latter not being subject to exhaustion, takes advantage of the necessary relaxations of the former, and rebounding, like the stone of Sisyphus, recovers its lost ground, and renews the toil of its more powerful opponent.

Breathing is in a great measure the effect of this interminable contest between the elasticity of the lungs and the irritability of the diaphragm.

The cause of the successive contractions of the diaphragm, in those cases at least in which the will is not concerned, seems to admit of the following explanation. A permanent and invariable load is sustained by its lower surface. By this load the relaxed muscular fibres become stretched to a degree which at length becomes painful and stimulating. To relieve itself from this irksome burden, the diaphragm is roused to contraction; but this contractile power, agreeably to the laws of muscularity, is soon exhausted, and falling into a quiescent state, allows the painful and stimulating distension of the relaxed fibres of the diaphragm to be again renewed. From the irksomeness of this condition it relieves itself by a fresh contraction. Thus, by the alternated superiority of two powers, on the balancing of which life itself depends, the chest is successively enlarged and diminished, and air alternately expelled and inhaled.

In a similar and equally effective manner, the elasticity of the lungs will be found to influence the movements of the heart and the motion of the blood. But as these movements are of a more complicated nature; as the consideration of them would lead into a long detail; and as my opinions respecting them are already fully recorded, I will not pursue the inquiry farther at this time.

In investigating the manner in which the elasticity of the lungs is rendered subservient to the great functions of respiration and the circulation, I shall be found, I trust, to have opened to the views of the physiologist, a new and a boundless field, which, I will venture to predict, will reward every skilful and assiduous cultivator with a rich harvest of discovery.




J.s Basire, sc.